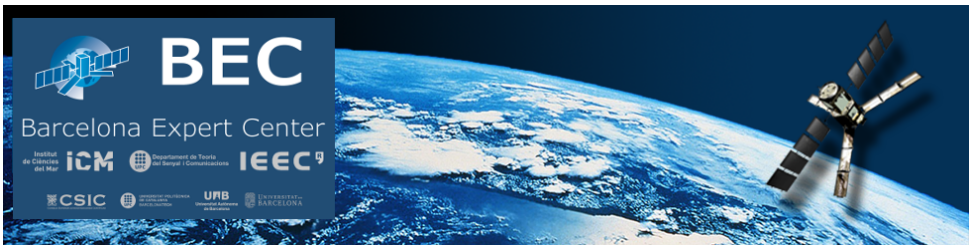

File: BEC-SMOS-0002-PD-Land.pdf , version 1.0

Title: SMOS-BEC Land Products Description.

Authors: BEC Team.

Contact: smos-bec@icm.csic.es

Date: 22/10/2018

SMOS-BEC LAND PRODUCTS DESCRIPTION

Abstract: This technical note describes the products distributed by the BEC team through its data visualization and distribution service http://bec.cmima.csic.es

Contents

1 INTRODUCTION

The ESA's Soil Moisture and Ocean Salinity (SMOS) mission is an innovative Earth Observation satellite launched on November 2009 to remotely sense soil moisture over the land surfaces and sea surface salinity over the oceans ([Kerr et al., 2010], [Font et al., 2010]). The SMOS single payload is the Microwave Imaging Radiometer using Aperture Synthesis (MIRAS), a L-band 2D synthetic aperture radiometer with multiangular and full polarimetric capabilities. It is a completely new type of instrument, a technological challenge that has required the development of dedicated calibration and image reconstruction algorithms ([McMullan et al., 2008]).

The Barcelona Expert Center (BEC) is an ESA Expert Support Laboratory (ESL) dedicated to developing and testing new algorithms to improve the baseline SMOS Level 1 (L1) and Level 2 (L2) products. Also the BEC aims at generating higher added-value products of interest for a broad range of users.

The BEC land products are generated and distributed in an operational way. A detailed description of current land products is included in this document. In the near future, the inclusion of complementary remotely sensed products is envisaged.

2 LAND PRODUCTS

Three different types of land products are created and distributed by the BEC:

- Level 3 (L3) soil moisture products: the data used to compute these L3 products are the SMOS L2 soil moisture User Data Product (UDP) files, which are operationally generated by ESA and received at the BEC in near real time. They include some geophysical parameters (soil moisture, optical thickness, dielectric constant...), a theoretical estimate of their accuracy, flags and descriptors for the product.
- Level 4 (L4) soil moisture products: they are disaggregated soil moisture products with an enhanced spatial resolution. The L4 products are obtained from the synergy of SMOS L1C brightness temperature measurements with land surface temperature (LST) and Normalized Difference Vegetation Index (NDVI) data. In the near real time approach, LST and NDVI data are provided by Moderate Resolution Imaging Spectroradiometer (MODIS) measurements acquired by the University of Valladolid. In the delayed approach, there are two different options depending on the LST source: the SMOS-MODIS L4 products using MODIS from NASA's server and the cloud free L4 products using ERA-Interim from the European Center for Medium Weather Forecast (ECMWF) model.
- Fire risk products: they are derived from the aforementioned L4 soil moisture product and LST data from MODIS in near real time.

2.1 Level 3 soil moisture products

In order to generate the L3 soil moisture products, the SMOS L2 soil moisture UDP are first filtered. Then, they are combined into maps where the spatial resolution is the same than the daily SMOS L2 product, also known as Icosahedral Snyder Equal Area (ISEA) 4H9 grid (daily ISEA product at 15 km), or into a spatial averaged grid, i.e., the Equal Area Scalable Earth (EASE)-2 grid (daily, 3-day, 9-day monthly and yearly binned product at 25 km). A comprehensive evaluation of these

products using two complementary small-scale and large-scale *in situ* networks and a surface water balance model has been performed in [González-Zamora, 2015]. Results showed that BEC L3 soil moisture estimates were consistent with ground based measurements in the time series comparisons, with Pearson correlation coefficients (R) and an Agreement Index (AI) higher than 0.8 for the total average and the land-use averages, and higher than 0.85 for the soil-texture averages.

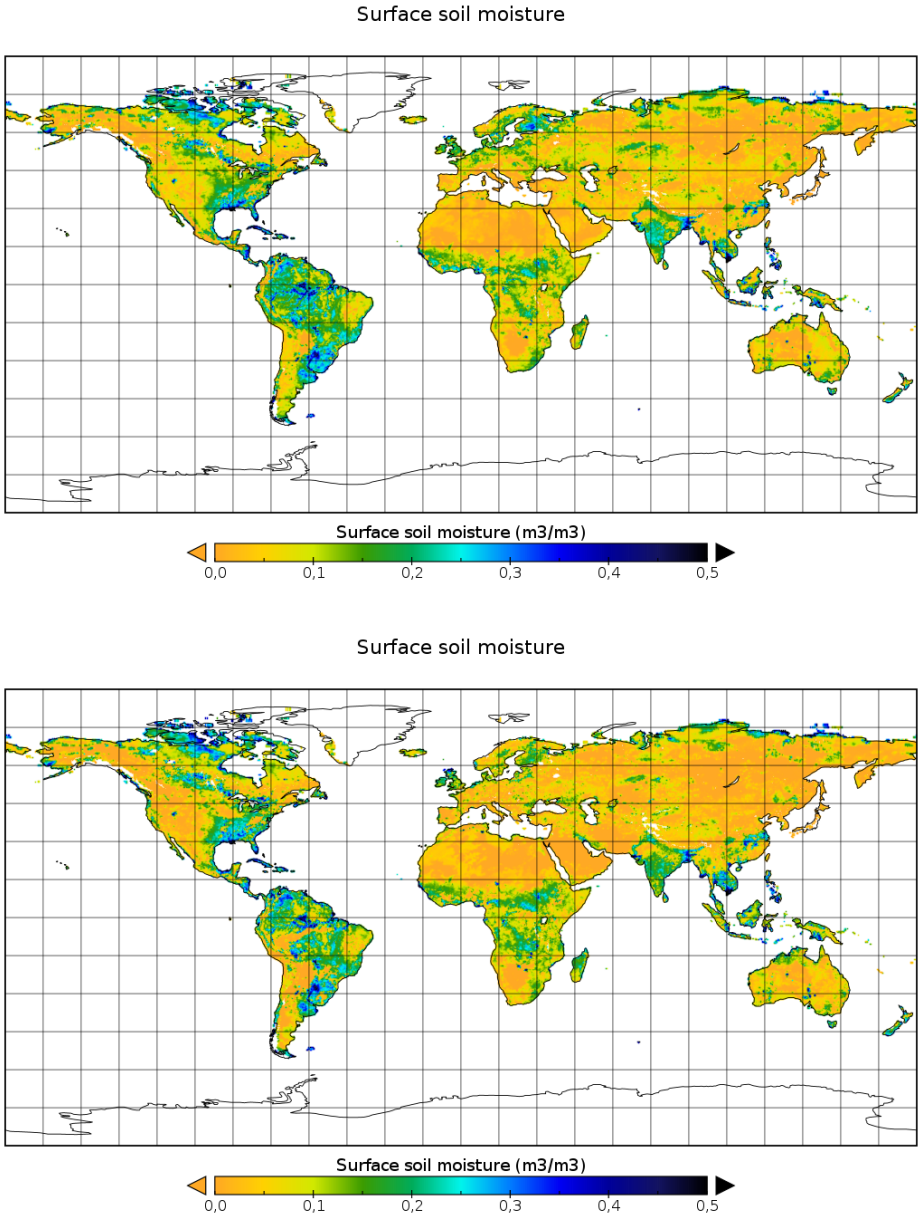

Figure 1: SMOS L3 surface soil moisture binned maps corresponding to the annual mean of 2017 for ascending (top) and descending (bottom) orbits.

2.1.1 Soil moisture data filtering

The quality flags and descriptors from UDP files allow discarding unreliable soil moisture values. The following filters have been applied to create L3 products:

- Grid points with negative values of soil moisture are discarded.
- Grid points with Data Quality Index (DQX) values greater than 0.07 are discarded.
- Grid points with the no product flag raised are discarded. It indicates that the retrieval has failed either due to retrieved geophysical data is not of an acceptable quality or other factors.
- Grid points with the probability of RFI flag set to high are discarded.
- Grid points with the out-range flag raised are discarded. It indicates that the retrieved geophysical data are outside the extended range.

2.1.2 ISEA land product

Daily maps of soil moisture, optical thickness and dialectric constant (real and imaginary part) are directly constructed from L2 UDP products with neither spatial nor temporal averaging. Ascending and descending orbits are processed separately. The resulting product contains:

- Latitude
- Longitude
- Grid point ID (ISEA grid point identifier)
- Soil Moisture value (m^3/m^3)
- Data Quality Index value for the soil moisture estimate. It is a measure of the standard deviation error in the estimate (m^3/m^3)
- Optical thickness at the nadir direction (Np)
- Data Quality Index value for the optical thickness estimate (Np)
- Real part of retrieved dielectric constant
- Data Quality Index value for the real part of retrieved dielectric constant
- Imaginary part of retrieved dielectric constant
- Data Quality Index value for the imaginary part of retrieved dielectric constant

2.1.3 Binned land products

Daily soil moisture maps in a EASE-2 25 km grid are constructed by DQX-weighted averaging. The spatial averaging of soil moisture in the cell k is computed following the expression:

$$\langle SM \rangle_k = \sum_{i=1}^{N} w_i SM_i, \quad \text{where} \quad w_i = \frac{\frac{1}{DQX_i^2}}{\sum_{j=1}^{N} \frac{1}{DQX_j^2}}. \tag{1}$$

The averaging of the associatd DQX ($\langle DQX \rangle_k$) is computed as:

$$\frac{1}{\langle DQX \rangle_k^2} = \sum_{i=1}^{N} \frac{1}{DQX_i^2}. \tag{2}$$

The averaged spatial variance of the soil moisture estimates (Var_k) is computed as:

$$Var_k = \frac{\sum_{i=1}^{N} \frac{1}{DQX_i^2}}{\left(\sum_{i=1}^{N} \frac{1}{DQX_i^2}\right)^2 - \sum_{i=1}^{N} \frac{1}{DQX_i^4}} \left(\sum_{i=1}^{N} \frac{SM_i^2}{DQX_i^2} - \langle SM \rangle_k^2 \sum_{i=1}^{N} \frac{1}{DQX_i^2} \right) \tag{3}$$

Ascending and descending orbits are processed separately. These products are created in a variety of averaging periods (and generation rates): 1 day (daily), 3 days (daily), 9 days (every 3 days), 1 month (monthly) and 1 year (annually) (see Table 1).

The fields given per grid cell are:

- Soil Moisture ($\langle SM \rangle_k$ of equation 1)
- DQX ($\langle DQX \rangle_k$ of equation 2)
- Variance of SM averaged in each cell (Var_k of equation 3)
- Number of L2 soil moisture estimates used in the computation (N of equation 1)

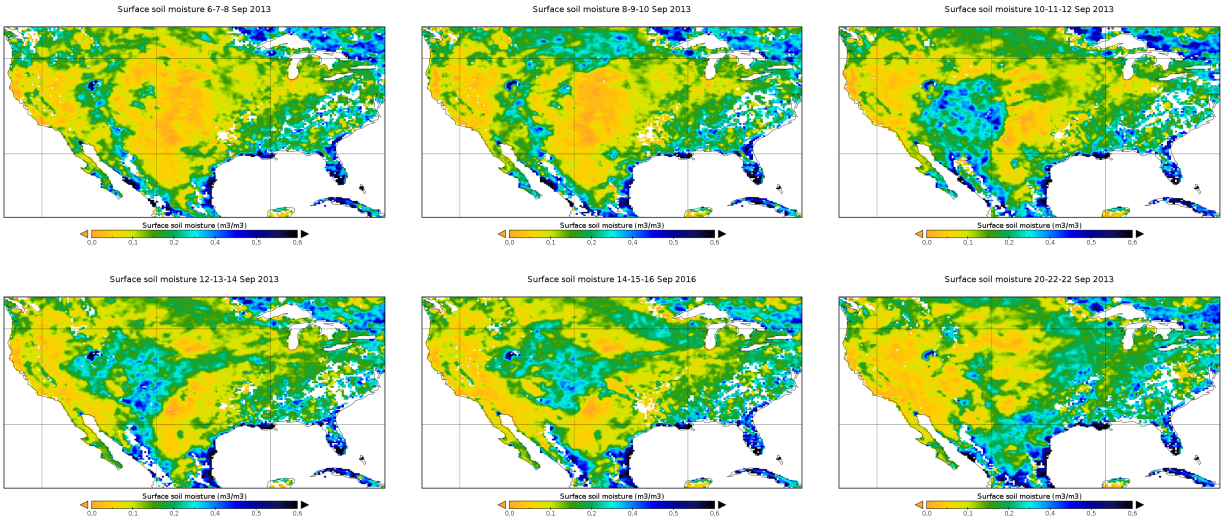

Figure 2: SMOS L3 soil moisture 3-day binned maps. The plots show the soil moisture evolution in Colorado, where heavy rain was received from 11 to 16 of September 2013.

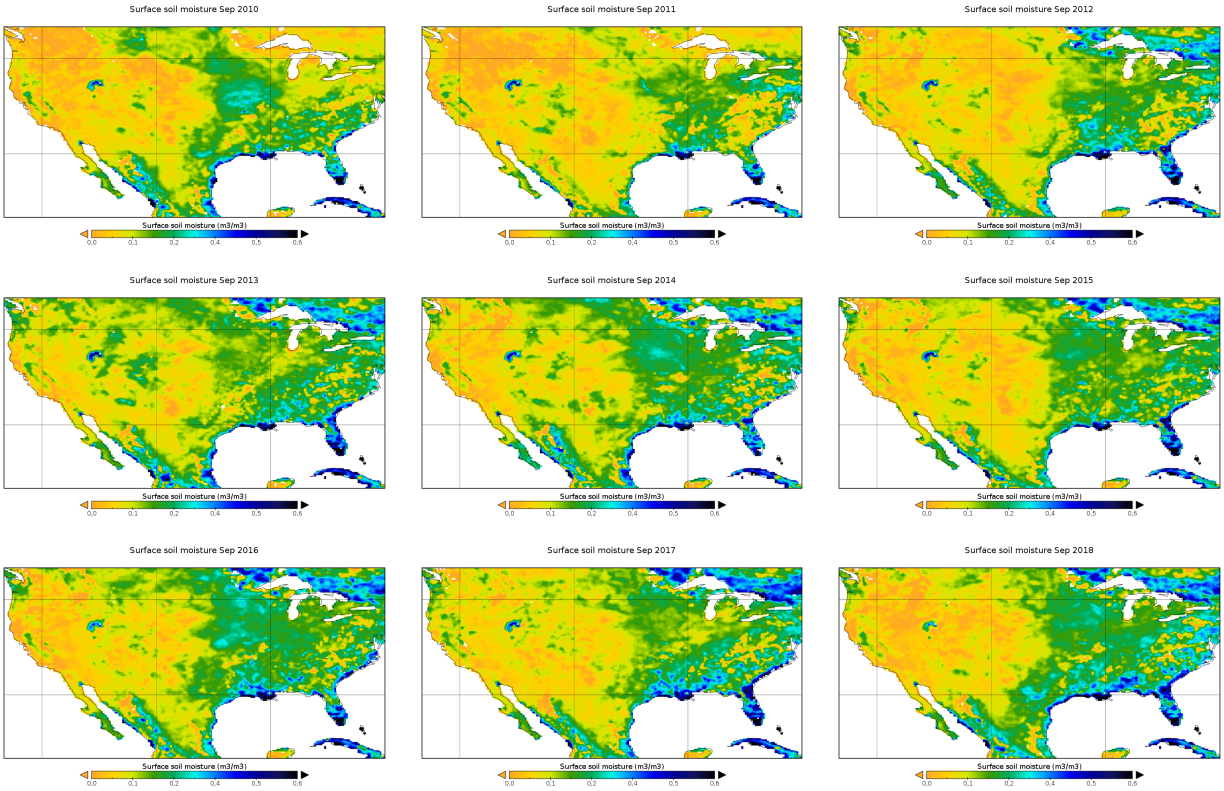

Figure 3: SMOS L3 soil moisture monthly binned maps. The plots show the mean values of September for the nine years of the mission in the same region.

2.2 Soil moisture Level 4 products

The ESA's SMOS is the first satellite mission ever designed to measuring soil moisture. Its accurate observations helping to improve our understanding of water and energy fluxes interactions between the atmosphere, the soil surface and subsurface at a global scale. However, its spatial resolution (on the order of tens of km) prevents SMOS data from being applied in small or regional scale applications, such as on-farm water management, flood prediction or meso-scale weather forecasting.

One key research line at BEC is the development of data fusion algorithms to provide downscaled SMOS-based soil moisture information resolving the dynamics within 100 m to 1 km catchments. Accurate knowledge of the soil moisture status at these scales is essential to understand how to manage and utilise soil water -one of the Earth's scarcest and most valuable natural resource- to its maximum potential.

An innovative downscaling approach for SMOS has been developed, which combines MODIS Visible/Infrared (VIS/IR) data with SMOS L1C brightness temperatures into high-resolution soil moisture maps. To date, validation results from comparison with in situ data over a selected suite of representative sites support the use of this technique; high resolution soil moisture maps are shown to nicely reproduce soil moisture dynamics at 1 km without a significant degradation of the root-mean-squared error with respect to the ESA's SMOS L2 product [Piles et al., 2011], [Sanchez-Ruiz et al., 2014], [Piles et al., 2014].

This algorithm has been implemented at BEC facilities and high resolution soil moisture maps over

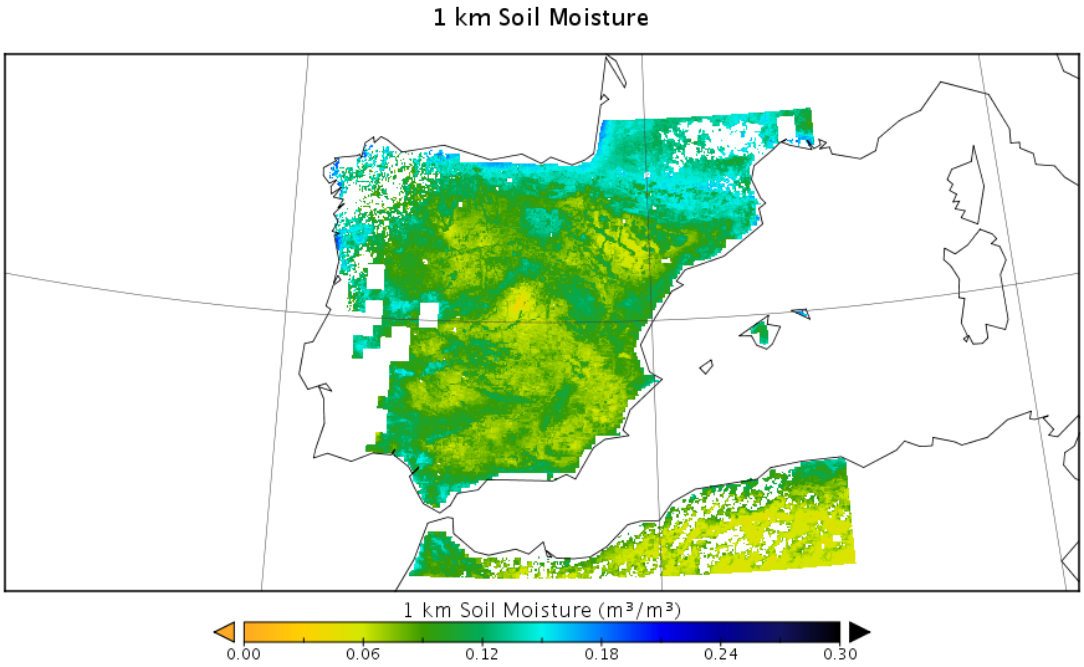

Figure 4: Disaggregated SMOS soil moisture map at 1 km spatial resolution over the Iberian Peninsula, from July 7, 2012 (6 A.M.) using the proposed algorithm. Empty areas in the image correspond to clouds masking MODIS observations or quality-filtered SMOS TB.

the Iberian Peninsula and other particular regions are being distributed: maps from the first six years of SMOS in orbit are available (delayed mode) and two near real-time maps are daily generated corresponding to ascending and descending overpasses with a delay of less than 12 hours. These maps are already being used as supporting information for forest brigades within the Catalonia region [Piles et al., 2013].

2.2.1 High resolution soil moisture: delayed approach

A data set of soil moisture maps covering the Iberian Peninsula at 1 km spatial resolution from June 2010 to December 2016 is provided. It contains two maps per day, corresponding to SMOS ascending (6 A.M.) and descending (6 P.M.) passes. Maps are obtained using the downscaling algorithm in [Piles et al., 2014], which combines the brightness temperature measurements from ESA SMOS L1C, with LST (land surface temperature) and NDVI (Normalized Difference Vegetation Index) data from Aqua MODIS day passes. The latest released SMOS data is available at BEC; MODIS version 5 MYD11A1 products are freely distributed by the U.S. Land Processed Distributed Active Archive Center (http://www.lpdaac.usgs.gov). In version 3.0, ERA-INTERIM information is used in the LST/NDVI space to provide soil moisture estimates under cloud free conditions [Piles, 2015].

2.2.2 High resolution soil moisture: near real-time approach

Soil moisture maps covering the Iberian Peninsula at 1 km of spatial resolution are provided in near real-time (delay <12 h). Two maps per day are generated, corresponding to SMOS ascending (6 A.M.) and descending (6 P.M.) passes. Maps are obtained using the downscaling algorithm in [Piles et al., 2011], which combines the brightness temperature measurements from ESA SMOS L1C, with LST and NDVI data from Terra/Aqua MODIS day passes. The use of MODIS Terra LST is pref-

ered. Nevertheless, downscaled maps using LST yield broadly consistent results in [Piles et al., 2014]. Hence, Aqua is used when Terra LST is not available (i.e. masked by clouds). SMOS latest released data in near-time time is available at BEC facilities; MODIS data in near real-time is kindly provided by the Laboratorio de Teledetección de la Universidad de Valladolid (LATUV, http://www.latuv.uva.es).

2.3 Fire risk maps

Fires are a concerning topic, especially in the Mediterranean area, due to their future increase in number and extension as a consequence of climate change. Their environmental, economic, and safety impacts explain the need of near real time fire risk indices and maps in order to improve prevention and extinction actions. As soils water content clearly influence the water content of fuels, soil moisture is a key variable in fire risk. As shown in [Chaparro, 2014], fire ignition was more probable to occur in the North-East of the Iberian Peninsula under dry soil conditions (as seen by SMOS), when compared to unburned areas.

Since 2012, BEC high resolution soil moisture maps in NRT are being routinely used by the Diputació de Barcelona (DiBa) for fire risk assessment and prevention during the forest fire season (June-September). SMOS-derived fine-scale soil moisture information is being included in DiBaś fire risk prevention service daily bulletin with the purpose of detecting areas with extreme dryness posing a risk of forest fire. This daily bulletin is used by DiBa to decide where to deploy the forest fire prevention agents within the Barcelona province. With five years of data, it is now possible to detect soil moisture anomalies leading to spring and autumn fires. In [Chaparro, 2015] a relationship is shown between SM, land surface temperature, and burned area. This relationship is used to to obtain BEC Fire risk maps at 1 km spatial resolution in near real-time. They are obtained using Soil Moisture L4 and Land Surface Temperature from MODIS and ECMWF, both absolute values and anomalies with respect to the 2011-2014 period. Four risk levels are defined, each associated with a threshold of minimum burned area: Level 0 represents a low fire risk, Level 1 corresponds to a risk of ignition (fires of up to 500 ha), Level 2 is linked to big fires (> 500 ha), and level 3 represents a risk of super big fires (>3000 ha).

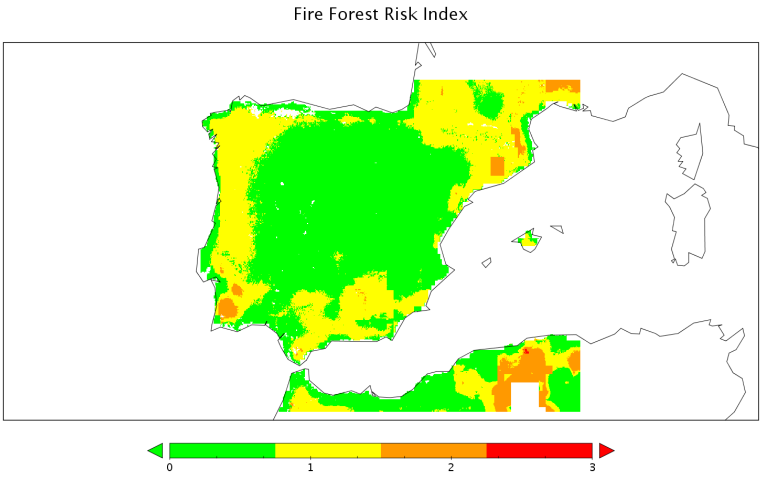

Figure 5: Fire risk map obtained for the Iberian Peninsula and Balearic Islands, from August 9, 2013.

The modelling and validation datasets have been based on more than 2,000 fires occurring in the Iberian Peninsula and Balearic Islands for the period 2010-2014. Concerning to validation, 94% of

fires were predicted. All fires >3000 ha were found at least in an ignition risk area, and 67% were correctly classified in the risk of fires >3000 ha category. BEC has recently been chosen as an Early Adopter for the NASA's SMAP (Soil Moisture Active Passive) mission, to foster the use of remotely sensed soil moisture data in forest fire risk prevention services.

2.4 Land files structure

SMOS BEC Land products are distributed in netCDF format with the following naming convention:

`BEC_AAAAAA_B_CCCCCCCCCCCCCCC_DDDDDDDDDDDDDDD_EEEEEEE_FFF_GGG.nc,`

where each field of the filename is as follows:

- `AAAAAA`: is the product's name:
  - `BIN_SM`: L3 Soil Moisture products
  - `HDE_SM`: L4 high resolution delayed soil moisture products
  - `HNR_SM`: L4 high resolution near real time soil moisture products
  - `RSK_FF`: L4 Fire risk maps in near real time
- `B`: indicates the orbit composition of the product.
  - `A` for ascending orbits
  - `D` for descending orbits
- `CCCCCCCCCCCCCCC`: starting UTC time (YYYYMMDD_hhmmss) of the half-orbit used to create the product.
- `DDDDDDDDDDDDDDD`: ending UTC time (YYYYMMDD_hhmmss) of the half-orbit used to create the product.
- `EEEEEEE`: internal code
  - `NOMINAL`: for L3 product indicates that the nominal filter (described in section 2.1.1) has been applied to L2 product
  - `AQUA1__`: for L4 product indicates that LST data at 1km spatial resolution from AQUA has been used
  - `TERR1__`: for L4 product indicates that LST data at 1km spatial resolution from TERRA has been used
- `FFF`: grid indicator
  - `025`: Indicates that EASE2-ML grid of 25 km is considered
  - `4H9`: ISEA 4H9 grid resolution
  - `IBE`: Indicates that the product is provided for the Iberian Peninsula
  - `SAF`: Indicates that the product is provided for South Africa
  - `GHA`: Indicates that the product is provided for Ghana
- `GGG`: version number of the file starting at 001

2.5 Land products list

The list of land products and their correspondance with the SMOS DPGS products and other data is summarized in tables 1 and 2, respectively.

In order to automatically download a given type of product, a Linux-based tool named *getBEC* is offered to users. Registered users can download this tool from http://bec.icm.csic.es/bec-tools/

Grid resolution	Type	Product	Generation rate	Averaging period	Orbit passes	Code
15 km	NRT SSM	ISEA	daily	1 day	ascending	XXXSMB001D4H9A
					descending	XXXSMB009D4H9D
25 km	NRT SSM	Binned	daily	1 day	ascending	XXXSMB001D025A
					descending	XXXSMB001D025D
				3 days	ascending	XXXSMB003D025A
					descending	XXXSMB003D025D
			every 3 days	9 days	ascending	XXXSMB009D025A
					descending	XXXSMB009D025D
			monthly	1 month	ascending	XXXSMB001M025A
					descending	XXXSMB001M025D
			annually	1 year	ascending	XXXSMB001Y025A
					descending	XXXSMB001Y025D
1 km	NRT SSM	High resolution	daily	1 day	ascending	XXXSMH001DIBEA
					descending	XXXSMH001DIBED
	Delayed SSM	High resolution	daily	1 day	ascending	XXXSMH001DIBEA
					descending	XXXSMH001DIBED
	NRT Fire risk	High resolution	daily	1 day	ascending	XXXSMH001DIBEA

Table 1: Land products distributed by BEC: surface soil moisture (SSM) and fire risk maps. Three first letters of the code indicated as XXX are NRT for near real time and DEL for delayed products. Code string is necessary to automatically download a given product using *getBEC* tool

BEC product	Version	SMOS DPGS processor	Other data
L3 soil moisture	v.001	L2 v.551	–
	v.002	L2 v.620	–
	v.003	L2 v.650	–
L4 soil moisture	v.001	L1C v.505 and L2 v.551	Aqua/Terra MOD/MYD11A1 v5 and Terra MOD13A2 v5
	v.002	L1 v.620 and L2 v.620	Aqua MYD11A1 and Terra MOD13A2 v5
	v.003	L1 v.620 and L2 v.620	ECMWF ERA-Interim and Terra MOD13A2 v5
Fire risk	v.001	L4 v.003	Aqua MYD11A1 v5

Table 2: Correspondance between BEC products and SMOS DPGS products.

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